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Cross-brand validation of grid services using V2G-enabled vehicles in the Parker project

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***Abstract*—The Parker project seeks to experimentally validate that contemporary series-produced electric vehicles (EVs), capable of V2G, are ready to participate in a number of both known as well as new and advanced grid services. In such services the timing, size and direction of power and energy exchanged between the EV battery and grid is controlled as to support either a single building, the local neighborhood or the regional power system. Vehicles purposely designed for such services are referred to as grid integrated electric vehicles (GIVs). The field of research, describing how GIVs may be used to actively support the power system is called Vehicle-Grid Integration (VGI).The purpose of this paper is to present how the Danish Parker project has systematically categorized a range of grid services, collected in a service catalog, and then, illustrate state-of-the-art EVs ability to support such services through experimental validation. Results are presented for three different tests performed in Parker; marginal emission factor charging, frequency containment reserves and a performance test for controlling power setpoints. The ultimate aim of this paper, and the Parker project, is to promote the GIV concept so that it may inform the design and capabilities of present and future EVs, EV supply equipment (EVSE) and communication standards.**

***Keywords*—Grid Integrated Electric Vehicle, Electric Vehicles, Smartgrid, V2G, Vehicle-Grid Integration**

I. Introduction

ELECTRIFICATION of transportation is a key component in meeting international CO_2 reduction commitments. The immediate effect of such electrification will be both a challenge, due to a new demand for power and energy, but also an opportunity in having the vehicles become active assets that may support the power system.

The research field of vehicle-grid integration (VGI) explore not only the adverse effects of electrification in terms of grid impacts and overloading, but also the potential benefits in the form of services that electric vehicles (EVs) can bring to the power system. VGI research has been documented in countless publications and R&D projects [1-14].

A service can be defined as the act of influencing the timing, size and direction of power and energy exchanged between the EV battery and an external load or electric network to provide value not related to transportation. The nature of services, dealing with everything from loading issues in the distribution system to acting as mobile loads in Vehicle-To-Tool applications, has vastly different requirements to the abilities and performance of the EV and the electric vehicle supply equipment (EVSE). Namely the support of vehicle-to-grid (V2G) and the speed with which power can be controlled may determine the range of services that an EV and its EVSE may be able to provide.

One of the main developments in the field of VGI is the support of V2G through DC chargers supported by the CHAdeMO protocol. This approach, where the power conversion is left to the EVSE and the EV thereby readily may enable V2G through the CHAdeMO standard, has allowed a broader support of V2G than ever before.

One of the main purposes of the Parker project [1] and the main novelty of this paper is; first, to describe the taxonomy used to systematically describe the range of services that EVs may provide and which has been collected in a service catalog. Second, to presents the experimental validation of state-of-the-art EVs from Nissan, Mitsubishi and PSA to test their ability to provide advanced, V2G-based, services. By proving the VGI readiness of such vehicles the authors hope to set a standard which may guide the design of future EVs to unlock their potential in supporting a stable, economic power system based on renewable energy with an increasing degree of autonomy.

This paper is organized as follows: first, related work will be described in a ”State of the art” section, next the section ”Power and energy services” will describe the services identified and explored by the Parker project. Then, the section ”Experimental validation” will describe the components and configuration used in the test-setup and present data from three different tests. Finally, the paper will conclude on study presented in this paper and contemplate future work.

II. State of the art

A 1997 publication by Prof. Kempton [2] marked the onset of modern VGI research and the exploration of V2G technology. Since this potential was first described, Prof. Kempton has led a number of scientific and commercial activities to prove that bidirectional EVs can provide power services to the power systems. Willett *et al.* have proven how slightly retrofitted EVs, primarily based on AC charging, may provide power balancing on a commercial basis [3], [4]. Prof. Kempton has initiated collaboration with multiple automobile OEMs proving the technical ability to support V2G across several different EV brands.

Later, inspired by the work of Prof Kempton, the Danish Nikola project [5] sought to systematically list and investigate the services that an EV may provide to power systems by developing a first version of the service catalog describe later in this paper. Nikola also sought to experimentally validate services on different brands of EVs [6] using AC chargers with dynamic power limitation using the IEC 61851 standard. The project also started the first Danish research efforts on testing frequency containment reserves (FCR) provision using V2G [7]. Finally, the project thoroughly investigated how EVs may provide local grid services through both simulation and experimental efforts [8], [9].

Currently a new generation of VGI projects have been launched, focusing on field testing using both AC and DC charging, and with support of V2G. This includes the French GridMotion project [10], the Danish ACES project[11], and the Califonia-based INVENT project [12].

In addition to the R&D efforts in the projects above, Copenhagen is also currently host of the worlds first commercial V2G hub [13]. Here, the utility Frederiksberg Forsyning is collaborating with Nissan, Enel and NUVVE, and the utilities fleet of e-NV200 vans has since fall 2016 participated in the frequency containment reserve market. The Parker project is connected to this pilot trough data sharing in order to promote scalability and replicability of this solution. While the commercial pilot at Frederiskberg Forsyning and the projects mentioned above illustrate the maturing of the technology, there are still neither standards that fully support VGI nor any international norm on what constitutes a GIV.

The Parker project builds on the experience and learning from previous R&D while leveraging new technological developments, specifically the V2G support from new DC chargers and CHAdeMO. This allows the Parker project to be the first project to experimentally validate the ability to provide DC-based V2G across several contemporary, unmodified, EV models. The validation is both performed by testing some of the most demanding services today, i.e. Frequency Containment Reserves(FCR) [14], but also by using a test cycle for measuring the performance of EVs and EVSEs in responding to a power request. The latter investigation of performance may allow us to understand how EVs may support future, even more demanding services and meet emerging grid codes [15].

III. Power and energy service

One of the objective of the Parker project has been to suggest a systematic and comprehensive listing of the services an EV may provide. Services can roughly be divided into categories according to the graphical level at which the are aimed and can create value. Fig. 1 illustrates these different domains that the EV owner may choose to actively support.

For each of the above domains, EVs can offer services that support:

- **Region**, balanced and economical power systems based on renewable energy.

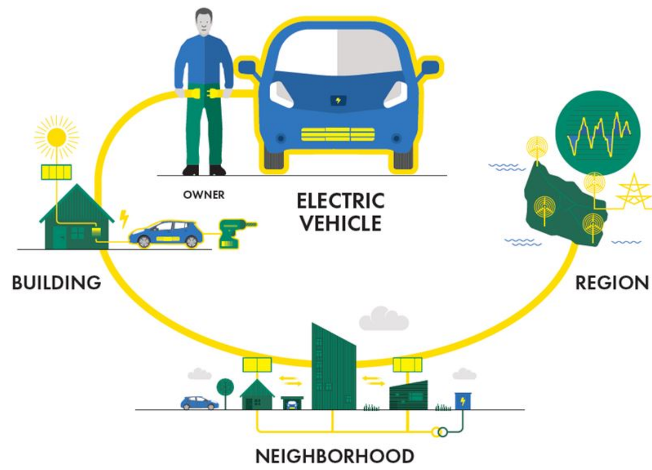

Fig. 1. Vehicle-Grid Integration - possible uses of the EV

- **Neighborhood**, local distribution grids and new urban energy infrastructures and communities.
- **Building**, energy-optimized buildings with local production.

The above classification, based on the geographical domain, may be more intuitive than the classical power system hierarchy - transmission system, distribution system and behind the meter. The three levels, however, still roughly corresponds to these levels of power systems.

Next, a total of six service categories are suggested and mapped to the levels above. Each category is meant to represent a logical grouping of related services. In Fig. 2 these six categories, used by Parker, are listed and some examples of services are provided for each category.

Below follows a brief description of each category:

- **Power balancing**, services relying on the battery and power electronics ability to provide high, instantaneous power (kW) for balancing purposes.
- **Energy balancing**, services that used the batteries ability to consume, store and return quantities of energy (kWh) for balancing purposes
- **Grid contingencies**, Services that support the safe and reliable operation of local distribution systems.
- **Energy Autonomy**, services that allow for energy autonomy by allowing an increasing degree of energy to be produced and consumed locally.
- **Islanded operation**, allow islanded operation when a connection to the power system is not practical or possible.
- **Mobile load serving**, services using the EV as a mobile source of power and energy where access to the power system is not practical or possible.

The emphasis of the Parker project has been on services at the regional level, especially power balancing, as well as services aimed at the neighborhood level in the shape of local grid contingencies. A number of specific services from these categories has then been selected for experimental validation. Some of these services will be presented in the next section.

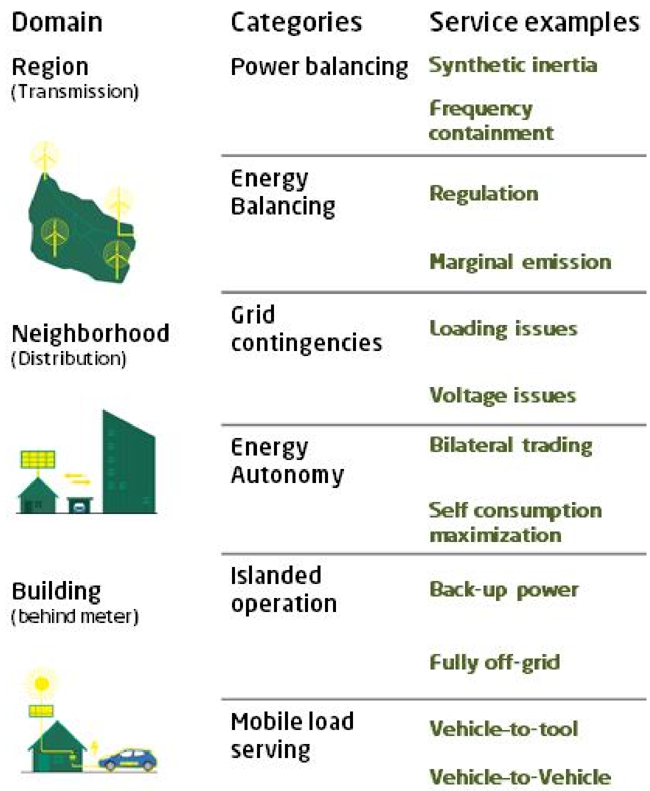

Fig. 2. Parker service catalog

IV. Experimental validation

The main components in Parker, used to conduct the experimental validation, are four EV models; Nissan Leaf, Nissan Evalia, Mitsubishi Outlander PHEV and Peugeot iOn, provided to the Parker project by partners Nissan, Mitsubishi Motors and PSA. The EVSEs used are provided by project partner Enel and are 10 kW bidirectional DC CHAdeMO chargers. All OEM vehicles are connected to the Enel EVSE and each constitutes a "EV/EVSE pair" used for testing. Since the EVSE is based on DC charging, it will contain the power electronics and inverters necessary to support V2G. i.e. for DC charging in particular, the EV cannot be seen in isolation but relies on the capabilities and performance of the EVSE connecting it to the power system.

The bidirectional powerflow between EV and EVSE is controlled trough an aggregator developed by project Partner NUVVE. For each test the NUVVE aggregator calculates and dispatches a power request which is sent to each EVSE. The EVSE then forwards the request to the EV using CHAdeMO messages. The power provided (bidirectional) by the EV is measured by a meter installed in the Enel chargers. This reference configuration is illustrated in Fig. 3.

A set of services from the Parker service catalog has been selected for experimental validation. Services has then been tested across all project vehicles to investigate cross-

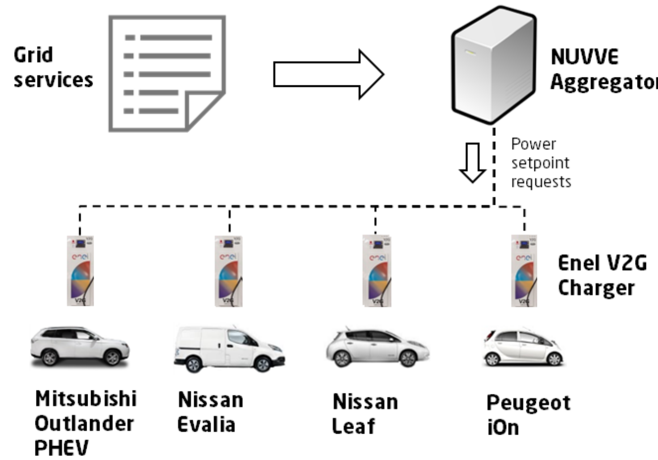

Fig. 3. Parker reference configuration

brand support. This section presents three different tests and describes the four EV models ability to provide them.

A. Service - Marginal Emission Factor

The first service belongs to the energy balancing category and is fairly easy to provide as it does not depend on V2G nor has high requirements in regards to activation time. This service can informally be referred to as smart charging and simply postpone charging until periods where it is more suitable to consume energy. Many EVs already support static smart charging where EV owners can specify a fixed time for charging to commence, e.g. informed by a time-of-use tariff. This particular service represents a dynamic smart charging scenario where the time suitable for energy consumption may change on a frequent basis and it therefor may be more practical to leave the charging control to a third party such as an EV aggregator.

Specifically, this service seeks to reduce the CO_2 production caused by charging. With sufficient energy data and forecasts it is possible to identify the hours where the added load of EVs is likely to cause the least additional CO2 emission considering the marginal production. A signal describing this marginal emission factor (MEF) has been explored in Parker in collaboration with the company Tomorrow.

In Fig. 4 (top) Requested power reflect the desire to have the EVs charge in hours with the lowest MEF value. The majority of energy is charged using a primary hour (0:03 to 1:03) which has the the lowest MEF and then topping of using one of the following hours with the second lowest MEF (3:03 to 3:15). All cars can be seen to follow the requested power rather accurately - The vehicles with smaller battery capacities can be seen to reduce the charging power (0:48 and 0:55) as the batteries are approaching full capacity.

The difference between power requested by the aggregator and the power provided by the vehicles is shown in figure Fig. 4 (bottom). While all EVs follow the requested power well some peaks are observed due to delays in vehicle response when a change in the power setpoint occurs.

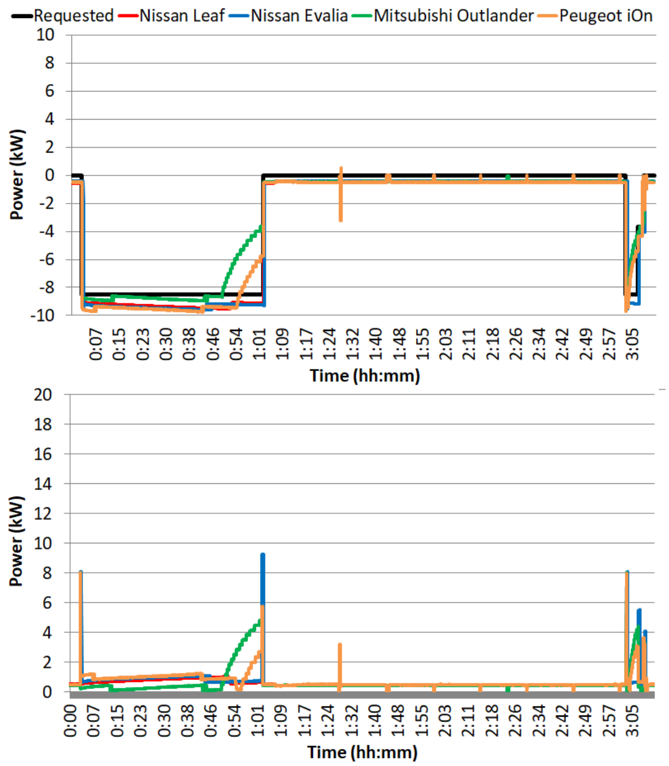

Fig. 4. Parker service - Marginal Emission Factor, (top) Requested and provided power for service (bottom) Absolute difference between requested and provided power

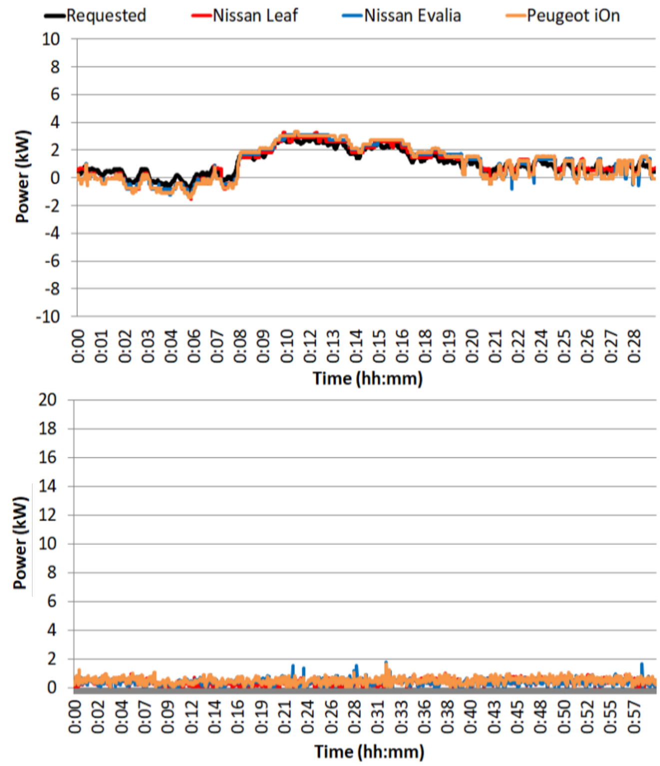

Fig. 5. Parker service - Frequency Containment Reserves, (top) Requested and provided power for service (bottom) Absolute difference between requested and provided power

B. Service - Frequency Containment Reserves

The second service differs from the MEF test as it both utilize V2G and requires a fast power response. To provide FCR an aggregtor would monitor the regional system frequency and dispatch a charge or discharge request to the EV according to a predefined droop function. Generally, the EVs will be set to charge if the frequency is high (according to a reference value or band), and discharge if the frequency is low.

FCR services has response requirements spanning from 150 sec down to 5 sec depending on the specific product provided. The ability to support V2G substantially strengthen an EVs ability to provide FCR.

This specific service is based on FCR provided in the western part of Denmark as part of the Continental Europe Regional group.

Figure Fig. 5 (top) shows the Requested power sent to all project vehicles and the corresponding response recorded by the EVSEs. It can be observed that the three vehicles participating in this test all are able to follow the bidirectional requested power set-point in a sufficiently precise and timely manner. It can be seen from Fig. 5 (bottom) that no large deviations between power requested and provided occur. This is because the power setpoints change more gradually in this test (without large steps).

C. Active power performance test

The last test does not represent a specific service but is rather designed to measure the performance of the vehicles and EVSEs. The test cycle suggested here, consist first of a continuous and then a step-wise variation of charging power set-points and can be said to be the most demanding of the three tests. This cycle allows for a measurement of, for instance, set point granularity (continuous portion) and response times (step-wise portion).

Fig. 6

A separate publication [15] elaborates on how the performance of the vehicles may be quantified using this test.

Based on the tests conducted in Parker, including the three above, the project has been able to conclude that the vehicle are ready and able to provide advanced grid services relying on a fast and bidirectional exchange of power.

V. Conclusion

This paper has described how the Danish Parker project have sought to systematically list, and then test EV services towards a number of contemporary unmodified electric vehicles using bidirectional DC chargers.The tests performed in Parker have validated that the Parker vehicles are ready to provide a fast bidirectional power response - allowing them to participate in a broad number of services. It represents a substantial stride forward for the field of VGI that a first generation of EVs can

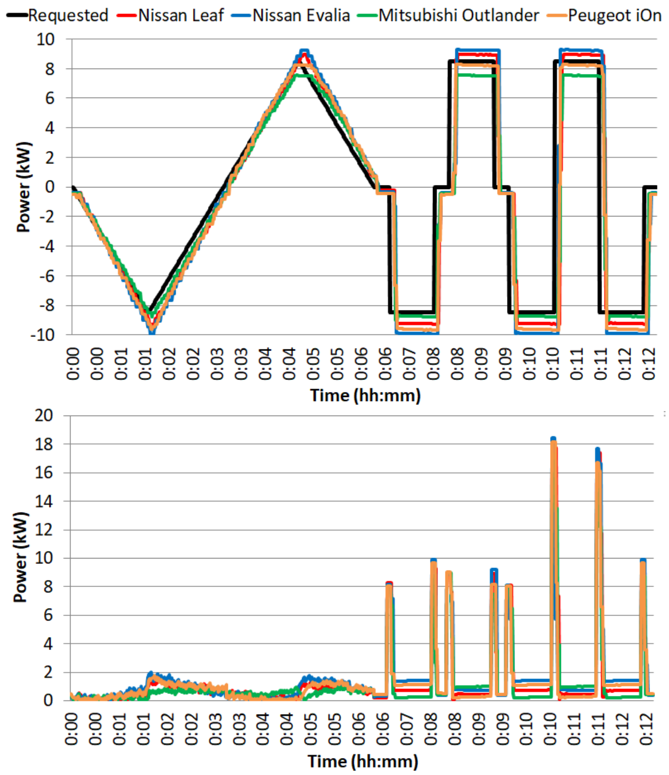

Fig. 6. Parker performance test - active power, (top) Requested and provided power for test (bottom) Absolute difference between requested and provided power

hereby be classified as grid integrated by being designed with power services in mind.

It is important to stress that these abilities are currently only available in series-produced EVs through novel DC-V2G chargers and use of the CHAdeMO protocol. For the broadest support, these capabilities need to cover both DC and AC charging as well as other charging interfaces and standards; most notably the ISO/IEC 15118 and CCS standard.

While the Parker project has successfully proven the V2G readiness of the participating vehicles, further improvements may further extend the number of services that EVs can offer. By decreasing the response and activation time of the EV-EVSE pair, even more time-critical power balancing services may be provided. Also, adding new capabilities such as reactive power provision and islanding support would extend services that EVs can provide. Finally, a main recommendation of the Parker project is to pursue a common definition of a grid integrated vehicle. i.e. the capabilities and performance that an EV should posses to be able to claim V2G and grid readiness.

Acknowledgment

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